The Distribution of Atomic Hydrogen Around Two Irregular Galaxies

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ABSTRACT

We present radio interferometric observations of two irregular galaxies that were candidates for having unusually extended HI emission. The galaxies, UGC 199 and DDO 26, otherwise appeared to be normal, low-luminosity systems with modest star-formation rates. To a detection limit of 2–3$\times10^{19}$ cm^{-2} at a resolution of about 50″, however, the HI around neither galaxy is unusually extended compared to other irregulars. The HI around UGC 199 appears as a regular, symmetric distribution with regular rotation and a maximum rotation speed of about 80 km s^{-1}. By contrast, the HI around DDO 26 shows a concentration into two blobs with an arm in the outer parts to the northwest and some additional emission to the northwest of that. The kinematical major axis is approximately 75° from the HI and optical morphological axis which is unusual for Im galaxies. In addition the velocity field in the outer parts of the galaxy is messy and the velocity profiles at the two HI peaks are broad. We suggest that DDO 26 has been perturbed externally or may be two dwarfs in the process of merging.

Subject headings: galaxies: irregular — galaxies: ISM — galaxies: individual (UGC 199, DDO 26) — galaxies: kinematics and dynamics

1. Introduction

The atomic hydrogen gas in and around galaxies is the material out of which star-forming clouds are derived and, hence, the HI plays a crucial role in the evolution of galaxies. We have long been intrigued by the gas that extends beyond, and sometimes well beyond, the optical galaxy. In most irregulars, as in most spirals, the HI extends to about twice the Holmberg radius R_H,

defined as the radius at a photographic surface brightness level of 26.7 magnitudes per arcsec^2 (see Figure 13 of Hunter [1997] and references therein for a compilation of HI extents). However, some galaxies have gas extending as far as $7R_H$.

In order to determine the role of this extended gas in the life of irregular galaxies, we began a radio interferometric study of the gas around those with particularly large HI extents at high enough resolution to see interesting structure if it were present. The general questions we are addressing are: 1) What is the structure of extended gas disks around irregular galaxies; 2) What role does this potential gas reservoir play in the evolution of the galaxies; and 3) Can large primordial gas disks around irregulars survive without disruption? These questions are important to understanding the internal processes and evolution of irregulars, which are the most numerous type of star-forming galaxy. Additionally, if, as studies of damped Lyα systems indicate, the majority of galaxies were larger HI clouds in their youth (Rao, Turnshek, & Briggs 1995), nearby irregulars with large gas envelopes are local examples of high redshift damped Lyα systems, and this has been substantiated with observations of one such irregular that lies directly in front of a QSO (Bowen, Tripp, & Jenkins 2001). Understanding the state of these envelopes helps us understand the process of galaxy formation.

Two of the galaxies whose extended gas disks we have studied so far turned out to have HI envelopes that are most definitely *not* regular, quiescent disks. NGC 4449 is nearly surrounded by a large arc of gas that spans roughly 80 kpc (Hunter et al. 1998). Interestingly, not only is this gas cold (velocity dispersions of 5–10 km s^{-1}), but it is also in regular rotation about the center of the galaxy. HI maps of IC 10 show that the extended gas is concentrated in three arm-like structures, and that IC 10 is merging with a large infalling cloud currently to the south of the disk (Wilcots & Miller 1998). A third galaxy, Sextans A, by contrast, does appear to have a smooth outer HI envelope (Wilcots & Hunter 2001).

To increase our sample, we obtained observations of two galaxies that were candidates for having unusually extended HI gas: UGC 199 and DDO 26 (=UGC 2053). UGC 199 was chosen from the Arecibo Observatory mapping of van Zee, Haynes, & Giovanelli (1995). DDO 26 was chosen from the list of Hunter & Gallagher (1985) that was derived from comparing HI fluxes obtained with single-dish radio telescopes with different beam sizes: the NRAO 140-foot and the NRAO 300-foot telescopes with beam sizes of $21'$ and $10'$, respectively. We present the results of new interferometric observations of these two galaxies here, and show that, in fact, neither of them is likely to have unusually extended HI emission.

Properties of UGC 199 and DDO 26 are given in Table 1. Both systems are classed as Im galaxies and were not known to be interacting systems. DDO 26 has an M_B that is comparable to that of the SMC. We do not yet have an M_B for UGC 199, but an estimate by van Zee et al. (1995) from a photographic magnitude would place UGC 199 as 2 magnitudes fainter than DDO 26. The star formation rates derived from Hα luminosities are also given in Table 1. DDO 26 has a star formation rate per unit area that is between that of the SMC and LMC. UGC 199's star

formation rate is 16 times lower and is typical of irregulars (Hunter 1997). Thus, both objects are relatively low luminosity and appear to be fairly typical Im galaxies.

2. Observations

2.1. HI

We obtained 21 cm line-emission observations of UGC 199 and DDO 26 with the Very Large Array (VLA[1]) radio interferometer in its D-array configuration on 5 August 2000. We chose the D-array configuration in order to maximize sensitivity to low column density extended emission. Characteristics of the observations and maps are given in Table 2. The total bandwidth was 1.56 MHz with 128 channels and a channel separation of 12.2 kHz (2.6 km s^{-1}). The data were on-line Hanning-smoothed, and the resulting velocity resolution is 5 km s^{-1}.

We subtracted the continuum emission in the *uv*-plane using line-free channels on either end of the spectrum. To make maps, we employed a routine in NRAO's Astronomical Image Processing System (AIPS) that enables one to choose a sample weighting that is in between the standard "natural" weighting, which gives the highest signal-to-noise but at the expense of long wings in the beam, and "uniform" weighting, which gives the best resolution but at the cost of signal-to-noise and the presence of negative sidelobes. We chose a sample weighting that gives a formal increase of only 5% in noise yet with a significant improvement in beam profile over what would have been achieved with "natural" weighting. The resulting synthesized beam profiles (FWHM) are given in Table 2. We also experimented with natural-weighted maps and with maps smoothed to twice the beam-size in order to explore possible missed emission at low column densities.

We deconvolved the maps until there were roughly comparable numbers of positive and negative components. To remove the portions of each channel map without emission that are only contributing noise to the map, we used the maps smoothed to twice the beamsize for a conditional transfer of data in the unsmoothed maps. The channel maps were blanked wherever the flux in the smoothed maps fell below 2.5σ. Flux-weighted moment maps were made from the resulting data cube.

2.2. V-band Images

We obtained V-band images of UGC 199 with the Perkins 1.8 m telescope at Lowell Observatory 1998 December and 1999 January. We used a SITe 2048×2048 CCD binned 4×4. The pixel scale was $0.61''$ and the seeing was $2.2''$. The night was clear. We took three 750 s

[1] The VLA is a facility of the National Radio Astronomy Observatory (NRAO), itself a facility of the National Science Foundation that is operated by Associated Universities, Inc.

exposures and combined them to remove cosmic rays.

DDO 26 was observed by P. Massey in V-band with the Kitt Peak National Observatory 4 m telescope 1997 October. The exposure was a single 60 s image. The detector was a Tektronix 2048×2048 CCD. The night was clear. The pixel scale was 0.42″ and the seeing was 1.6″.

The electronic pedestal was subtracted using the overscan strip. Images were flat-fielded using observations of the twilight sky.

3. The HI Results

3.1. UGC 199

To examine continuum objects in the field of view of the radio map of UGC 199, we constructed and deconvolved maps from the D-array *uv*-data before the continuum was subtracted. The 21 cm continuum emission is illustrated in Figure 1. An outer HI contour of UGC 199 is shown superposed to outline the galaxy. We have not detected any continuum emission from UGC 199 itself. Other sources in the field of view of the primary beam are listed in Table 3 along with their fluxes.

Channel maps of the HI line-emission in UGC 199 are shown in Figure 2. We detected HI from 1740 km s^{-1} to 1870 km s^{-1}. The channel maps show an elliptical distribution that does not change significantly from channel to channel and that appears to be similar to the beam shape. There is clear evidence of regular rotation.

The integrated HI map is shown superposed on our V-band image in Figure 3. The distribution is smooth and symmetrical. It is elongated at a position angle of $-77°$, close to that of the optical. The minor-to-major axis ratio of the HI is 0.77. If the intrinsic ratio is 0.3, as found in the optical for other irregulars by Hodge & Hitchcock (1966) and van den Bergh (1988), the observed ratio implies an inclination of 42°.

The flux in each channel of the HI data cube was integrated over a square 21′ on a side in order to determine the total HI flux detected in the map. The flux was corrected for attenuation by the primary beam. The integrated profile is shown in Figure 4 and compared to the single-dish profile obtained by Schneider et al. (1990). The beam of that observation was 3.3′, and so it is no surprise that our VLA observation detects more gas. We detect a total HI mass of 8.5×10^8 $M_\odot$. For comparison van Zee et al. (1995) give a total HI mass of 8.1×10^8 $M_\odot$. Thus, our VLA map includes 5% more HI. Maps of our data made with lower resolution but higher signal-to-noise do not detect any more flux.

Velocity field contours are shown superposed on our V-band image in Figure 5. There is clear and regular rotation at a position angle of $-82°$, close to the major axis of the integrated HI distribution. We have determined a rotation curve in the following manner. We began by

allowing all parameters to be variables and fitting the entire field with a Brandt function. From the resulting solution we fixed the center coordinates at 00^h 20^m 50.9^s, 12° 51′ 39″ (epoch 2000). We then fit the inner 40″ radius of the velocity field with solid body rotation and from that fixed the systemic velocity at 1800.5±2.0 km s^{-1}. This agreed to 0.3 km s^{-1} with the systemic velocity determined from the fit with the Brandt function as well. We then fit tilted ring models to annuli of 20″ width. Here the position angle was fixed at −82° from Figure 5 and the inclination at 42°, as discussed above. The resulting rotation curve is shown in Figure 6. We see UGC 199 attains a rotation speed of about 80 km s^{-1}, for an inclination of 42°.

3.2. DDO 26

To examine continuum objects in the field of view of the radio map of DDO 26, we constructed and deconvolved maps from the D-array *uv*-data before the continuum was subtracted. The 21 cm continuum emission is illustrated in Figure 7. An outer HI contour of DDO 26 is shown superposed to outline the galaxy. We have not detected any continuum emission from DDO 26 itself. Other sources in the field of view of the primary beam are listed in Table 4 along with their fluxes.

Channel maps of the HI line-emission in DDO 26 are shown in Figure 8. We detected HI from 974 km s^{-1} to 1078 km s^{-1}. There is clear division into two emission peaks from 977 km s^{-1} to 1039 km s^{-1}. The channel maps also show an arm to the northwest of the galaxy center from 1031 km s^{-1} to 1068 km s^{-1}. We also display the integrated HI map in Figure 9 so as to bring out the arm.

The integrated HI map is shown superposed on our V-band image in Figure 10 and on the Hα image in Figure 11. The inner HI distribution is elongated along a position angle of 46°. This is rotated about 8° further to the east than the apparent position angle of the optical distribution that has a major axis position angle of 38° in the V-band (see also Swaters 1999). The outer HI contour is close to round even though the center of the HI distribution and the optical are clearly elongated. The second lowest contour, on the other hand, is more boxy than round. These changes in minor-to-major axis ratio with radius could indicate changes in inclination of the gas disk and be the result of a warp. Warps in gas disks are a common phenomenum, but usually in normal systems they are not as extreme as what we see here.

The integrated HI shows the two peaks with centers about 41″ apart. The H II regions are clustered around these two peaks. The arm seen in the channel maps is apparent as a bulging of the contours to the northwest of the galaxy center. There is also a piece of emission that appears to the northwest of the arm in channels 1057 km s^{-1} to 1075 km s^{-1} and appears in the integrated HI map as a knob on the outer contour.

The flux in each channel of the HI data cube was integrated over a square 21′ on a side in order to determine the total HI flux detected in the map. The flux was corrected for attenuation by the primary beam. The integrated profile is shown in Figure 12 and compared to the NRAO

140-foot Telescope single-dish observation of Hunter & Gallagher (1985) that used a beam of $21'$. In Figure 12 one can see that the 140-foot telescope and VLA profiles parallel each other, but the 140-foot profile is everywhere significantly higher. We detect a total HI mass of 1.1×10^9 $M_\odot$ while Hunter and Gallagher detected 2.0×10^9 $M_\odot$. Thus, we would appear to have detected only 56% of the HI detected with a single-dish telescope. We will return to this issue below.

Velocity field contours are shown superposed on our V-band image in Figure 13. The velocity field is fairly regular in the center, becoming disorganized in the outer parts. However, the major axis implied by the velocity field is about $-29°$ (Swaters 1999 measured $-37°$). This is 75° to the northwest of the position angle defined by the major axis of the inner HI distribution. Thus, the rotation axis is quite divorced from the morphology of the HI and optical.

How common is such a large difference in the position angle of the kinematic and morphological major axes in Im galaxies? To address this we examined the sample of Im and Sm galaxies observed by Swaters (1999). We selected from his sample those galaxies with organized velocity fields and with ellipticities greater than 0.1 so that the optical major axis would not be ambiguous. These criteria left 47 galaxies from his larger sample. We determined the difference between the position angles of his HI kinematical axis and his R-band optical morphological axis. We checked most galaxies and adjusted three position angles: one obvious typographical error (UGC 6446) and two that disagreed by large amounts with RC3 values and with our own V-band image (UGC 10310, UGC 11861). The resulting number distribution is shown in Figure 14. The position of DDO 26 is marked. One can clearly see that most Im and Sm galaxies have morphologies and velocity fields that agree within 10°, although there is a tail in the distribution up to 40° difference. Only three galaxies, including DDO 26, have differences larger than this, and all three have differences of 60°—70°. Thus, we see that while DDO 26 is not alone in exhibiting such a large difference, it is unusual compared to most Im and Sm galaxies.

We show a position-velocity diagram in Figure 15, for slices one beam-width wide along the optical major axis and the HI kinematic axis. The slice along the optical major axis reflects the two HI peaks and the intensity minimum between them. Otherwise the two slices show a very broad range in velocity at a given location. Figure 16 shows profile cuts at the locations of the two HI peaks, integrated over a square approximating the beam-size. One can again see the wide velocity width (44 km s^{-1} and 51 km s^{-1} FWHM). The higher intensity peak (labeled 1 in the figure) has a shallow fall-off to higher velocities and the lower intensity peak (labeled 2 in the figure) appears to be the blending of two Gaussians.

Clearly, DDO 26 is not kinematically relaxed. The dramatic change in the position angle of the HI distribution, the large offset between the kinematical and morphological major axes, the messy kinematics in the outer parts of the velocity field, the broad profiles of the HI peaks, and the HI arm to the northwest combine to suggest that this galaxy has been perturbed sometime in the recent past. There is no obvious perturbing galaxy nearby; the nearest large galaxy (NGC 1012) is 330 kpc on the plane of the sky and 42 km s^{-1} different in radial velocity. However,

the double peaked nature of the HI and optical suggest another possibility: that DDO 26 is two systems in the process of merging. In this scenario, the arm to the northwest would be the result of tidal forces. It is not always easy to tell galaxies that are irregular due to internal processes from galaxies that are irregular due to external processes. And certainly, normal Im galaxies are lumpy in the HI and optical. However, given the unusual characteristics of this system, a merging system is a possibility. If DDO 26 is two systems in the process of becoming one, the original systems must both have been small irregular galaxies to begin with because the mass and luminosity of the combined systems are low.

4. HI Extents

4.1. UGC 199

For UGC 199 we measure a maximum HI radius of $1.6'$ at the outer contour of 2.2×10^{19} cm^{-2} in Figure 3. Thus, the HI extent relative to the optical R_{HI}/R_{25} is only 3.6. Estimating R_H as 40% larger than R_{25}, we have $R_{HI}/R_H \sim 2.5$. From data compiled from the literature for Im galaxies, Hunter (1997) shows a peak in the distribution of R_{HI}/R_H of 1.5—2. Note, however, that Hunter's R_{HI} is the extent measured to 1×10^{19} cm^{-2}. The HI around DDO 26, therefore, is only marginally more extended than that of typical irregulars. There would have to be highly extended HI around UGC 199 at column densities 1—2×10^{19} cm^{-2} for the extent of the HI around UGC 199 to be much larger. Since our smoothed data which reaches this sensitivity limit does not pick up any more flux, this possibility seems unlikely.

4.2. DDO 26

For DDO 26 we measure a maximum HI radius of $2.4'$ at the outer contour of 3.1×10^{19} cm^{-2} in Figure 10. Thus, R_{HI}/R_{25} is 2.4. From Swaters' (1999) R-band $d_{25}/d_{26.5}$ ratio for DDO 26, we estimate $R_{HI}/R_H \sim 1.7$, a value that is typical for Im galaxies. Thus, there would have to be considerable gas 1–3×10^{19} cm^{-2} at large radii for DDO 26 to have unusually extended HI.

On the other hand, the comparison with Hunter & Gallagher's (1985) single-dish observations says that we have only detected 56% of the gas emission. Furthermore, Hunter and Gallagher would predict an HI diameter greater than $10'$, a factor of two larger than what we detect. There are three possible explanations. First, the extended emission is there but it is larger than the largest structure the VLA D-array is sensitive to and is absolutely smooth beyond our detection radius. This would require that the missing HI be extended $>15'$ radius. Since the two beam-sizes in Hunter and Gallagher's flux comparison were $10'$ and $21'$, this is possible.

Second, the missing emission is at a column density below our detection limit of $< 3 \times 10^{19}$. In the worst case scenario, the missing emission—9×10^{8} M$_\odot$ —would be spread evenly over an

annulus of radius from 2.4′, the extent of what we detect, to 10.5′, the half beam size of the Hunter & Gallagher (1985) observation. That would be a column density of 1×10^{19} cm^{-2}. Although Figure 10 only goes to 3×10^{19} cm^{-2}, we would easily have detected a column density of 1×10^{19} cm^{-2} in our smoothed map, and we do not see this emission.

The third, explanation is that Hunter & Gallagher (1985) goofed and, in fact, the HI emission associated with DDO 26 is not highly extended. That this might be the case is suggested by Figure 12 where the Hunter and Gallagher integrated profile matches our VLA profile closely in shape but the Hunter and Gallagher profile is offset to higher flux values. If the Hunter and Gallagher profile is sitting on a 0.03 Jy pedestal, a 9% error in the peak, the two profiles could be brought into agreement. If we were simply missing extended HI that Hunter and Gallagher had detected, we might not expect that missing flux to be so evenly distributed in velocity as Figure 12 suggests. Thus, this explanation seems the most likely.

5. Summary

We have presented VLA D-array observations of two irregular galaxies that were candidates for unusually extended HI emission. The galaxies, UGC 199 and DDO 26, otherwise appeared to be normal, low-luminosity systems with modest star-formation rates. Our VLA data suggest that the HI around these two galaxies is not unusually extended.

The HI around UGC 199 appears as a regular, symmetric distribution with regular rotation and a maximum rotation speed of about 80 km s^{-1}. We detect HI to 1.6′ at 2.2×10^{19} cm^{-2}. The ratio R_{HI}/R_{25} is 3.4 which is similar to values for other irregulars.

By contrast, the HI around DDO 26 shows a concentration into two blobs with an arm to the northwest and some additional emission to the northwest of that. The major axis of rotation is 75° from the morphological major axis, and this is unusual for Im and Sm galaxies. We suggest that DDO 26 has been perturbed in some way and that it could be two dwarfs in the process of merging. We detect HI to a radius of 2.4′ at 3×10^{19} cm^{-2}. R_{HI}/R_{25} is 2.4 which is typical of Im galaxies. However, we find that we are missing 56% of the flux detected in a single-dish observation and conclude that most likely the single-dish observation is in error.

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Table 1. Galaxy Characteristics.

Quantity	UGC 199	DDO 26	Reference
Morphological type	Im:	Im	RC3
D (Mpc)	29.8	17.3	RC3, $H_0 = 65$ km s^{-1} Mpc^{-1}
R_{25} (arcmin)	0.46	1.02	RC3
R_{25} (kpc)	7.9	5.15	RC3
$E(B-V)_f$	0.038	0.093	Burstein & Heiles 1984
$E(B-V)_t$[a]	···	0.50	Hunter & Hoffman 1999
M_B	···	−16.68	RC3
log $L_{H\alpha}$ (ergs s^{-1})	39.23	39.50	Hunter & Elmegreen 2001
log SFR/area ($M_\odot$ yr^{-1} kpc^{-2})[b]	−3.61	−3.57	Hunter & Elmegreen 2001

[a]$E(B-V)_t$ is used to correct the Hα luminosity for reddening, in conjuntion with the reddening law of Cardelli, Clayton, & Mathis (1989). For UGC 199, we assumed an $E(B-V)_t$=$E(B-V)_f$+0.1.

[b]The star formation rate per unit area (SFR/area) is determined from the Hα luminosity and a Salpeter (1955) stellar initial mass function integrated from 0.1 $M_\odot$ to 100 $M_\odot$ (Hunter & Gallagher 1986). The area is πR_{25}^2.

Table 2. HI Observations and Data.

Quantity	UGC 199	DDO 26
RA (2000)	00 20 51.4	02 34 29.4
DEC (2000)	12 51 39	29 45 05
Central velocity (km s^{-1})	1800	1034
Time on source (minutes)	140	145
Beam FWHM (arcsec)	55.2×46.9	51.0×45.5
Beam FWHM (kpc)	8.0×6.8	4.3×3.8
Single channel rms (Jy $beam^{-1}$)	0.94	0.96
Integrated HI ($M_\odot$)	8.5×10^8	1.1×10^9
R_{HI} to 3×10^{19} cm^{-2} (arcmin)	1.5	2.4
R_{HI}/R_{25}	3.3	2.4

Table 3. Continuum sources near UGC 199.

Object	RA (2000)[a]	DEC (2000)[a]	Flux (Jy)
1	00 20 55.8	13 13 32	0.232
2	00 21 41.2	13 10 30	0.014
3	00 20 10.5	13 10 43	0.108
4	00 21 58.1	13 03 07	0.019
5	00 19 51.8	13 02 03	0.014
6	00 19 37.6	13 02 41	0.013
7	00 19 44.7	12 58 21	0.038
8	00 19 46.5	12 54 53	0.026
9	00 22 31.0	12 57 03	0.030
10	00 20 28.3	12 52 57	0.078
11	00 20 36.3	12 47 32	0.017
12	00 20 33.6	12 46 40	0.007
13	00 20 33.6	12 43 25	0.031
14	00 20 16.8	12 37 08	0.016
15	00 19 47.5	12 28 15	0.092
16	00 21 44.7	12 33 01	0.021

[a]Units of RA are hours, minutes, and seconds.

[b]Units of DEC are degrees, arcminutes, and arcseconds.

Table 4. Continuum sources near DDO 26.

Object	RA (2000)[a]	DEC (2000)[a]	Flux (Jy)
1	02 34 36.4	29 57 52	0.005
2	02 33 40.4	29 56 33	0.007
3	02 35 00.4	29 50 17	0.004
4	02 35 03.3	29 46 23	0.005
5	02 33 31.5	29 47 27	0.005
6	02 33 44.5	29 42 54	0.026
7	02 34 19.4	29 33 36	0.020
8	02 33 55.5	29 32 44	0.008
9	02 33 37.6	29 30 46	0.004
10	02 34 58.3	29 29 42	0.006

[a]Units of RA are hours, minutes, and seconds.

[b]Units of DEC are degrees, arcminutes, and arcseconds.

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Fig. 1.— 21-cm continuum map of the region around UGC 199 is shown. The map has been corrected for the attenuation by the primary beam. The continuum sources are numbered as given in Table 3. The contour near the center is the outer HI-emission contour of UGC 199 shown in Figure 3, and is 2.2×10^{19} cm^{-2}. The beam size FWHM ($55.2''\times46.9''$) is shown as the elliptical contour in the lower left corner.

Fig. 2.— Channel maps of HI line-emission in UGC 199 made from VLA D-array observations. The inner $5.6'\times5.6'$ are shown. Every other channel from the data cube is shown. The beam size FWHM ($55.2''\times46.9''$) is shown in the final panel. Right Ascension is marked along the x-axis. The right tick marks an RA of 00^h 20^m 45^s; the left tick marks an RA of 00^h 21^m 00^s.

Fig. 3.— Integrated HI map of UGC 199 is shown as contours superposed on our V-band image of the galaxy. The HI contour levels are 2.2, 3.3, 14.5, 25.7, 36.9, 48.0, and 59.2×10^{19} cm^{-2}. The beam size FWHM ($55.2''\times46.9''$) is shown as the elliptical contour in the lower left corner.

Fig. 4.— Integrated HI profile of UGC 199 from our VLA D-array data. For comparison we also show the integrated profile from Schneider et al.'s (1990) observations of UGC 199 taken with the Arecibo Observatory and a $3.3'$ beam.

Fig. 5.— Contours of the velocity field of UGC 199 are shown superposed on our V-band image. The contours are 1750 km s^{-1} to 1840 km s^{-1} in steps of 10 km s^{-1}. The first and last contours are labeled. The beam size FWHM ($55.2''\times46.9''$) is shown as the elliptical contour in the lower left corner.

Fig. 6.— Best-fit rotation curve of UGC 199. The velocity field was fit in annuli $20''$ in width spaced every $20''$. We held the position angle fixed at $-82°$. This was determined from Figure 5. We also held the inclination angle fixed at $42°$. This was determined from the minor-to-major axis ratio of the integrated HI (Figure 3) and assumed an intrinsic ratio of 0.3 (Hodge & Hitchcock 1966, van den Bergh 1988). Determination of the central position and central velocity are discussed in the text.

Fig. 7.— 21-cm continuum map of the region around DDO 26 is shown. The map has been corrected for the attenuation by the primary beam. The continuum sources are numbered as given in Table 4. The contour near the center is the outer HI-emission contour of DDO 26 shown in Figure 10, and is 3.1×10^{19} cm^{-2}. The beam size FWHM ($51.0''\times45.5''$) is shown as the elliptical contour in the lower left corner.

Fig. 8.— Channel maps of HI line-emission in DDO 26 made from VLA D-array observations. The inner $9.75'\times9.75'$ are shown. The beam size FWHM ($51.0''\times45.5''$) is shown in the final panel. Right Ascension is marked along the x-axis: The right tick marks an RA of 02^h 34^m 15^s; the middle tick marks an RA of 02^h 34^m 30^s; and the left tick marks an RA of 02^h 34^m 45^s.

Fig. 9.— Integrated HI map of DDO 26 shown so as to bring out the arm to the northwest of the

center of the galaxy.

Fig. 10.— Integrated HI map of DDO 26 is shown as contours superposed on our V-band image of the galaxy. The HI contour levels are 3.1 12.5, 25.0, 37.5, 50.0, 62.5, 75.0, 87.5, 100.0, 112.5, 125.0, and 137.5×10^{19} cm^{-2}. The beam size FWHM ($51.0''\times45.5''$) is shown as the elliptical contour in the lower left corner.

Fig. 11.— Integrated HI map of DDO 26 is shown as contours superposed on our Hα image of the galaxy. The stellar continuum has been subtracted from the Hα image to leave only nebular emission. The HI contour levels are 3.1 12.5, 25.0, 37.5, 50.0, 62.5, 75.0, 87.5, 100.0, 112.5, 125.0, and 137.5×10^{19} cm^{-2}. The beam size FWHM ($51.0''\times45.5''$) is shown as the elliptical contour in the lower left corner.

Fig. 12.— Integrated HI profile of DDO 26 from our VLA D-array data. For comparison we also show the integrated profile from Hunter & Gallagher's (1985) observations using the NRAO 140-foot radio telescope which has a $21'$ beam.

Fig. 13.— Contours of the velocity field of DDO 26 are shown superposed on our V-band image. The contours are 1010 km s^{-1} to 1050 km s^{-1} in steps of 5 km s^{-1}. The first and last two contours are labeled. The beam size FWHM ($51.0''\times45.5''$) is shown as the elliptical contour in the lower left corner.

Fig. 14.— Differences between optical and HI kinematical position angles for a sample of 47 Im and Sm galaxies taken from Swaters (1999). We have marked the value for DDO 26.

Fig. 15.— Position-velocity plots for slices through the DDO 26 HI data cube. The top panel is a slice at the position angle of the optical major axis; the bottom panel, along the HI kinematic major axis. Each slice is a sum over one beam width through the center of the HI map. The contours in the top panel go from 0.025 to 0.2 in steps of 0.025 Jy beam^{-1}; in the bottom panel, from 0.025 to 0.25 in steps of 0.025 Jy beam-1.

Fig. 16.— Profile cuts through the two HI peaks seen in Figure 10. For each we have integrated over a square with a side equal approximately to the beam-size. Peak 1 is centered at $2^{\rm h}\ 34^{\rm m}\ 28.4^{\rm s}$, $29^\circ\ 44'\ 39''$; peak 2 is centered at $2^{\rm h}\ 34^{\rm m}\ 31.4^{\rm s}$, $29^\circ\ 45'\ 18''$.

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